TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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IONIZATION IN THE KNOCK ZONE OF AN INTERNAL-COMBUSTION ENGINE

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SUMMARY

The ionization in the knock zone of an internal-combustion engine was investigated. A suspected correlation between the intensity of knock and the degree of ionization was verified and an oscillation in the degree of ionization corresponding in frequency to the knock vibrations in the cylinder pressure was observed.

INTRODUCTION

When knock occurs in an internal-combustion engine, it is accompanied by increased pressures and temperatures in the cylinders owing to the rapid burning of the end gas. The violent chemical reaction and the accompanying increased temperatures of the gases in the knock zone suggest that the ionization of the gases is increased during the knocking cycle and, further, that this increase might be used to indicate the presence and the intensity of knock.

Ionization gaps have been used to measure velocity of flame travel by both Schnauffer and Schütz (references 1 to 3), but no published material seems to be available for the simple measurement of the degree of ionization in the knock region of an internal-combustion engine.

DESCRIPTION AND OPERATION OF APPARATUS

In order to investigate the degree of ionization in the knock zone of an internal-combustion engine, simultaneous records of cylinder pressure and ionization were obtained. A high-speed C.F.R. single-cylinder test engine was used. The cylinder-pressure indicator consisted of a quartz crystal pick-up unit, an amplifier, and a 9-inch cathode-ray oscilloscope. (See references 4 to 6.) The cylinder-pressure indicator was used to indicate knock.

A 5-inch oscilloscope (reference 7) was mounted directly above the 9-inch tube so that the two could be photographed simultaneously. The current passing between the points of a BG-3B2 spark plug placed in the knock zone controlled the vertical deflection of the cathode beam of the 5-inch oscilloscope and served as a measure of ionization.

The synchronizer unit (reference 8) contains two alternators that are directly connected to the crankshaft. One alternator generates six cycles per revolution of the crankshaft and is normally used for synchronization but was used, in these tests, as a marker. The marker voltage is supplied to both oscilloscopes by turning on the marker amplifier and closing switch S_2 (fig. 1). Thus points are located on the traces of both oscilloscopes corresponding to 60° angles of the crankshaft. From these records (see fig. 2) the horizontal time scale of the oscilloscopes can be calculated. The second alternator, which generates two cycles per revolution, was used for synchronization. The two alternators were interchanged to give a greater number of marker cycles on the records.

The capacitance between the leads of each oscilloscope and the spark-plug leads was sufficient to make a small break in the trace of each oscilloscope when spark occurred. These breaks are useful in finding corresponding points in the two oscilloscope traces. Both the pressure indicator and the ionization indicator were equipped with calibrating circuits for maintaining a constant overall amplification.

A moving-picture camera photographed both oscilloscopes so that records of several successive cycles of the engine were obtained.

ENGINE CONDITIONS

The ionization gap was placed in the knock zone at A in figure 3 and the cylinder-pressure indicator was installed at D. The spark plugs were at B and C.

The engine was operated at a speed of 2000 rpm with a compression ratio of 7, a spark advance of 30°, and a fuel-air ratio of 0.075. The fuel, the throttle setting, and the mixture temperature were varied, and the records were obtained under the various engine conditions listed in table I.

DISCUSSION OF RESULTS

Figure 4 shows ionization-current records of four successive cycles in which the engine knocked intermittently. The differences in the ionization records are quite striking. The maximum ionization current of the knocking cycles was approximately three times as large as that of the cycles in which knock did not occur. The knock records are also characterized by a short duration of the ionization current and by a rapid drop from peak ionization current to zero. In normal burning records, the ionization current dies out slowly. The high degree of ionization during knock may be attributed to the higher temperature of the end gas and the extreme violence with which the chemical reaction is completed. Because the combustion of the end gas is completed much faster, the duration of the ionization is shorter.

Figure 5 consists of three consecutive no-knock records showing both ionization and pressure diagrams with the engine operating on S-1 fuel at a mixture temperature of 100° F. These engine conditions gave the lowest ionization currents of those tested. The records in figure 6 are sample records obtained with S-1 fuel at a mixture temperature of 200° F. The ionization currents were slightly higher than those in figure 5 because of the increase in mixture temperature. The use of 100-octane Army gasoline plus 6 milliliters of ethyl fluid per gallon gave noticeably higher ionization currents. A comparison of figures 5 and 7 shows that the type of fuel apparently affects the degree of ionization. The ionization records in figure 7 were of the same general shape as other no-knock records, and their peaks were still much lower than those obtained under knocking conditions.

The engine was next operated with a commercial gasoline (69-octane) and at a mixture temperature of 100° F. Figure 8 consists of three successive cycles. The first cycle shows normal burning; the second, a slight knock; and the third, normal burning again. In figure 9, under the same test conditions, knock is present in all three cycles.

With the mixture temperature raised to 200° F, the engine knocked harder; three of these records are shown in figure 10.

Figure 11 shows a large-scale ionization current and pressure record of a knock cycle. The engine was operated with a commercial gasoline (69-octane) at a mixture temperature of 200° F. The record indicates the presence of a high-frequency oscillation of approximately 7000 cycles per second. The frequency of this oscillation corresponds to the knock vibration on the pressure record.

The time interval between the spark and the start of the ionization current becomes shorter when knock begins and the interval becomes increasingly shorter as the knocking becomes more severe. The time required for the flame to travel from the spark plug to the point where knock begins is approximately the same as in nonknocking explosions, but knock greatly accelerates the burning in the end zone; hence, the over-all time interval between spark and the beginning of ionization at the gap is shortened (references 2 and 9 to 12).

Table I lists both the average peak ionization currents and the maximum peak ionization currents obtained under various engine conditions. When intermittent knock was indicated by the pressure records, the ionization-current peaks of the knock and no-knock records were averaged separately.

Attention is called to the fact that a large increase in the ionization with knock is characteristic of the end gas of an engine; and, in order to use this phenomenon to indicate knock, the gap must be in this zone. In many cases it is impracticable to install a gap in the knock zone; furthermore, the position of the end gas may not be independent of engine speed. The high-frequency oscillation in the ionization current that is present when knock occurs is apparently independent of the position of the ionization gap. Work is now being done to investigate a knockmeter based on this principle.

CONCLUSIONS

1. Knock affects the ionization in the knock zone of an internal-combustion engine in the following ways:

a. Knock sharply increases the degree of ionization and, as knock becomes more severe, the intensity of ionization is further increased.

b. Knock shortens the duration of ionization.

c. After the ionization reaches a maximum, it falls to zero rapidly in knocking cycles.

d. Knock causes an oscillation in the degree of ionization corresponding in frequency to the knock vibrations in the cylinder pressure.

e. Ionization reaches the gap sooner in the cycle when the engine knocks.

2. The fuel affects the degree of ionization.

3. An ionization gap under proper conditions may be used to indicate knock.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 17, 1940.

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TABLE I

Test Conditions and Degree of Ionization

Fuel	Mixture temperature (°F)	Imep, (lb/sq in.)	Relative degree of ionization				Remarks
			Individual maximum ionization		Average of maximum ionization		
			No knock	Knock	No knock	Knock	
S-1	100	138	1.5	-	1.1	-	
S-1	200	123	2.5	-	1.5	-	
S-1	300	118	2.8	-	1.7	-	
S-1	300	-	-	14.0	-	10.7	Spark advanced to 50°, knocking lightly
100-octane Army fuel + 6 ml ethyl fluid	100	122	5.5	-	3.9	-	
100-octane Army fuel + 6 ml ethyl fluid	200	122	8.5	-	5.5	-	
100-octane Army fuel + 6 ml ethyl fluid	300	120	6.3	-	4.2	-	
100-octane Army fuel + 6 ml ethyl fluid	100	132	5.7	-	4.2	-	3/4 throttle
100-octane Army fuel + 6 ml ethyl fluid	100	141	3.2	-	1.7	-	Full throttle
Commercial gasoline (69 octane)	100	-	-	15.5	4.8	12.4	Intermittent knock
Commercial gasoline (69 octane)	200	110	-	20.0	-	20.0	Continuous audible knock

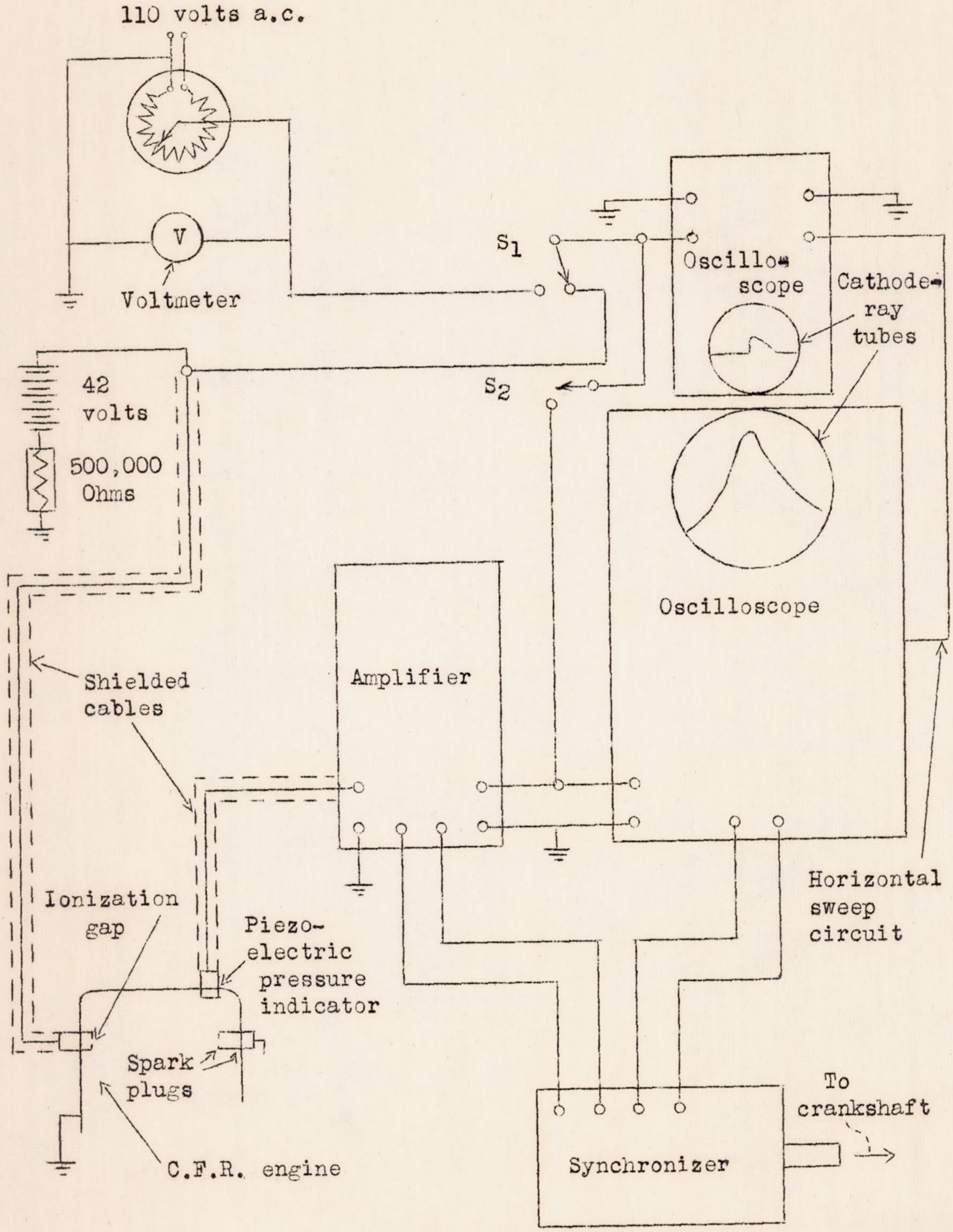

Figure 1.- Diagram of apparatus.

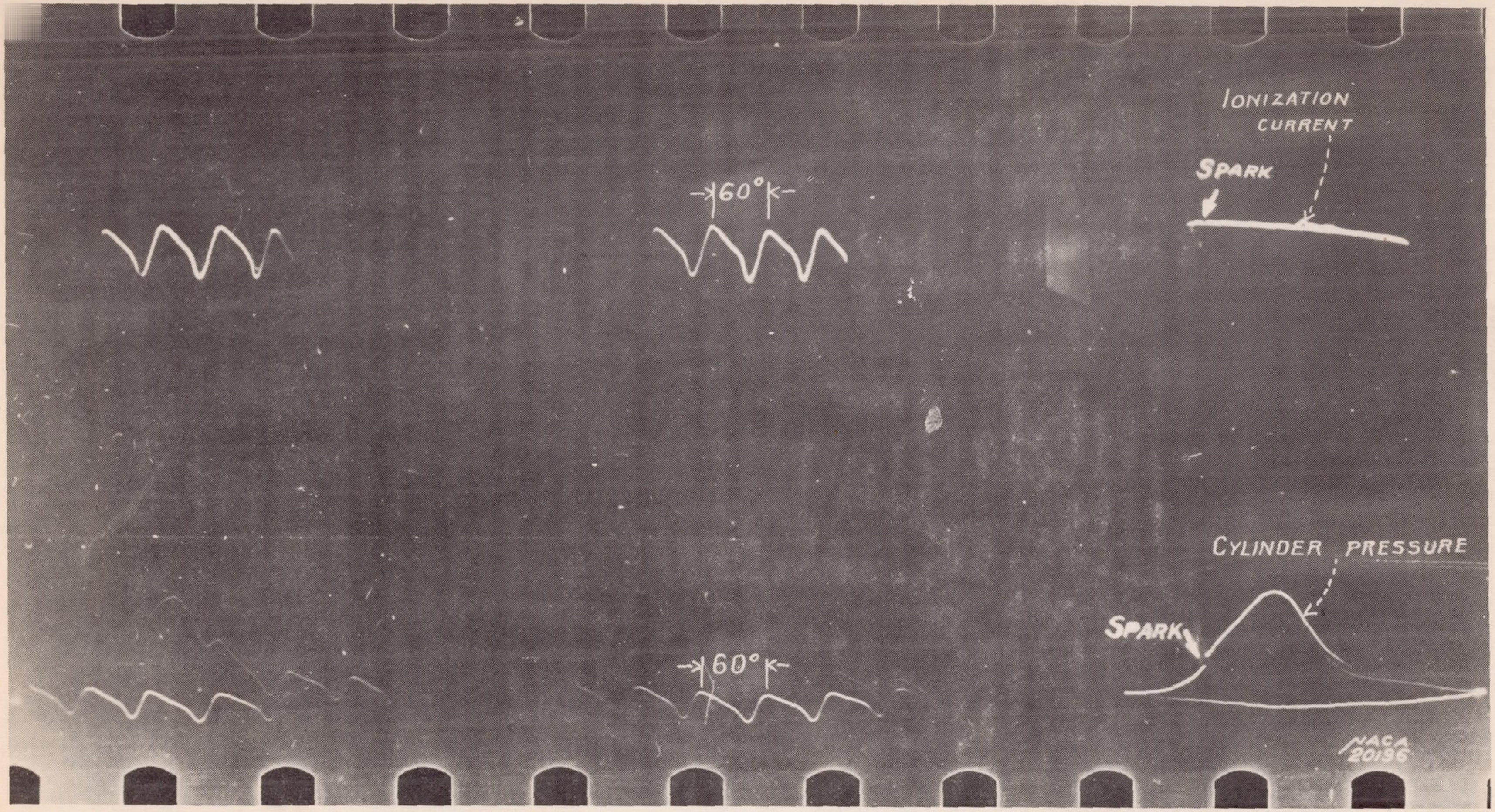

Figure 2.- Two marker records showing relative time on oscilloscope traces and ionization-current and cylinder-pressure diagrams, on which the position of spark is indicated.

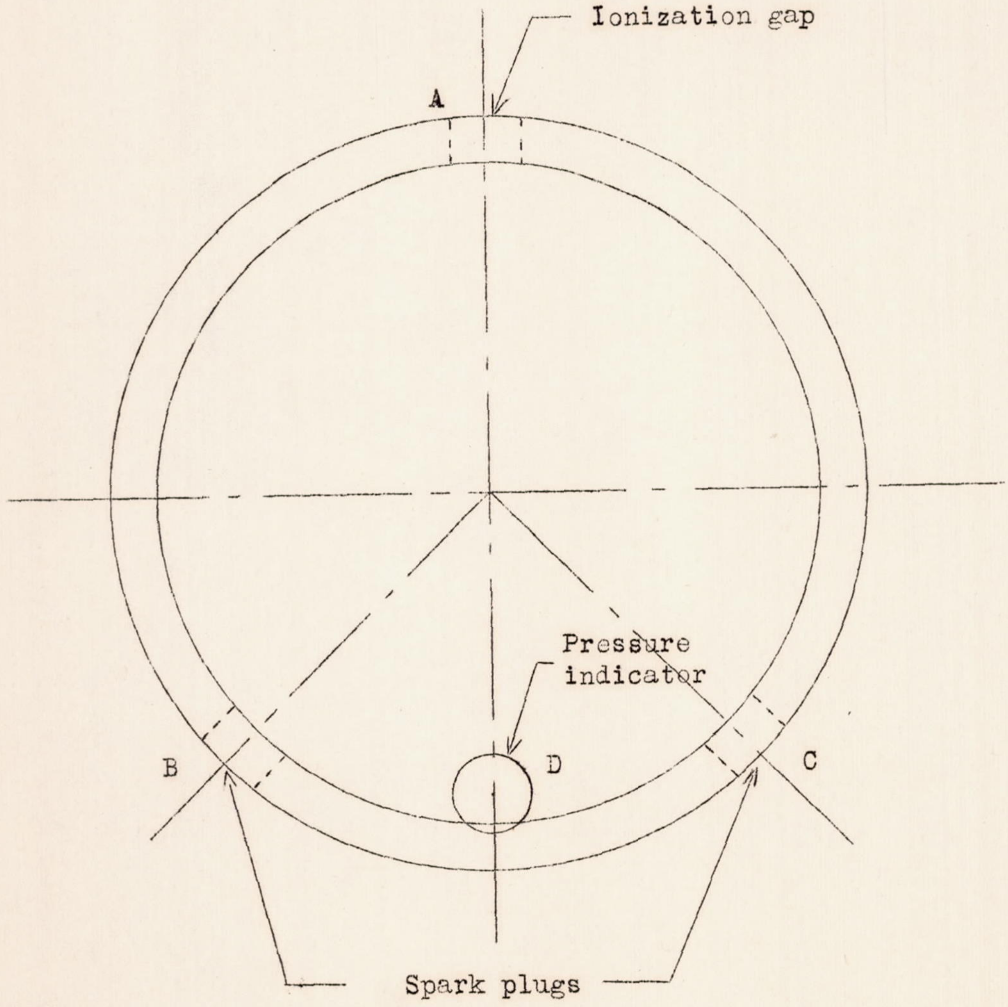

Figure 3.- Plan view of C.F.R. cylinder head.

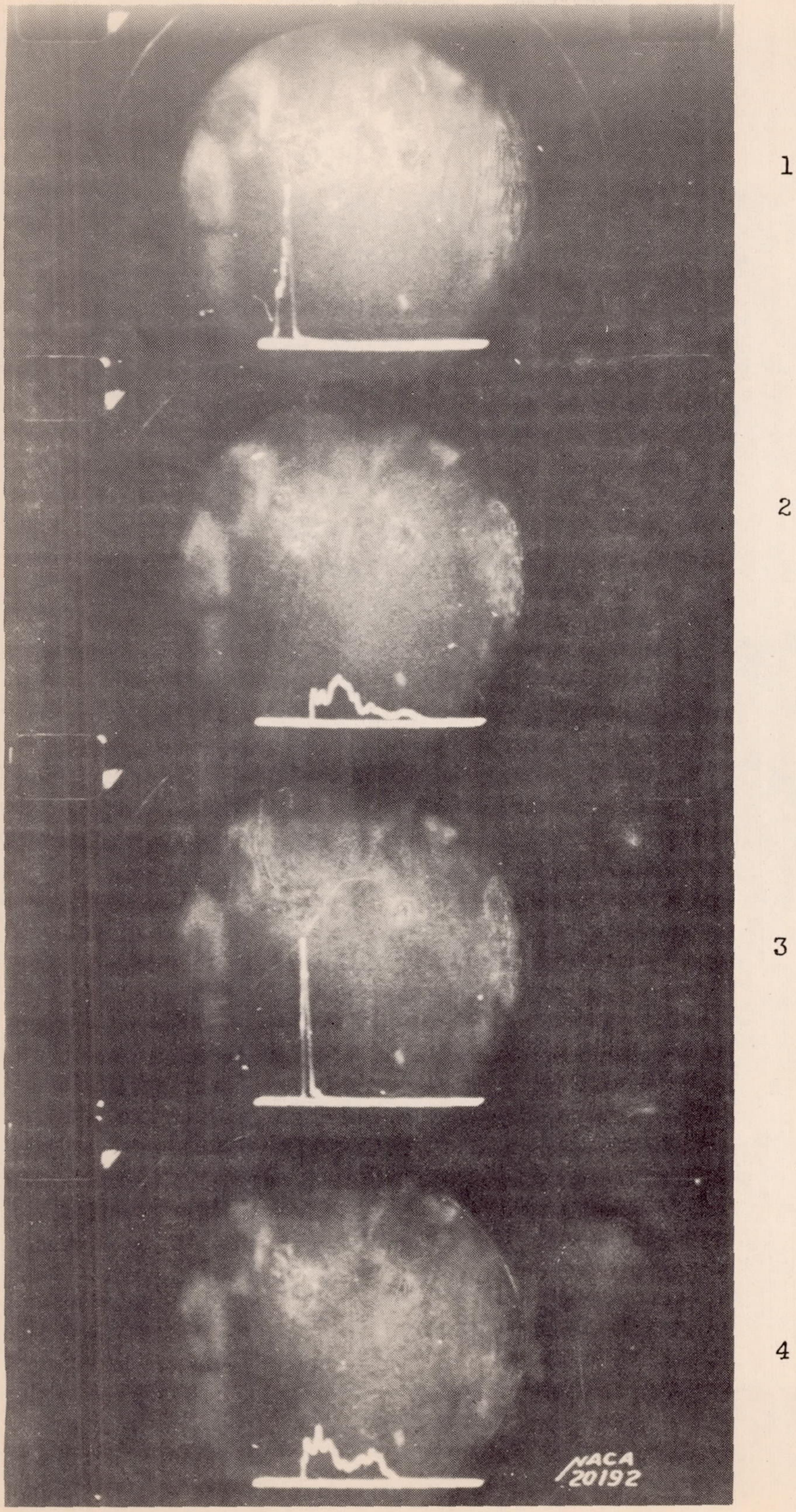

Figure 4.- Ionization-current records of four successive engine cycles. In the first and the third cycles, knock was present.

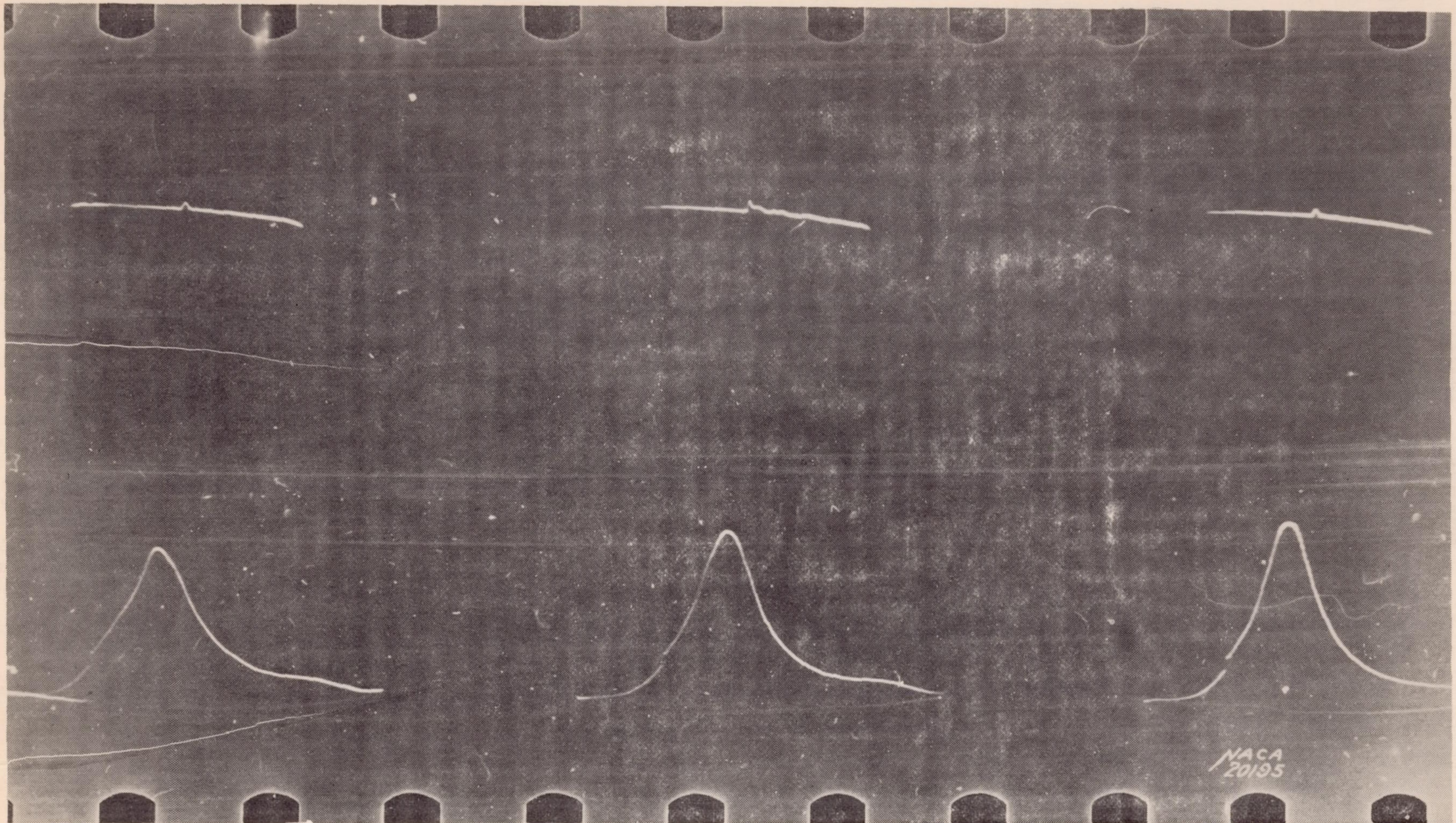

Figure 5.- Ionization-current and cylinder-pressure records of three successive cycles. No knock; fuel, S-1; mixture temperature, 100° F.

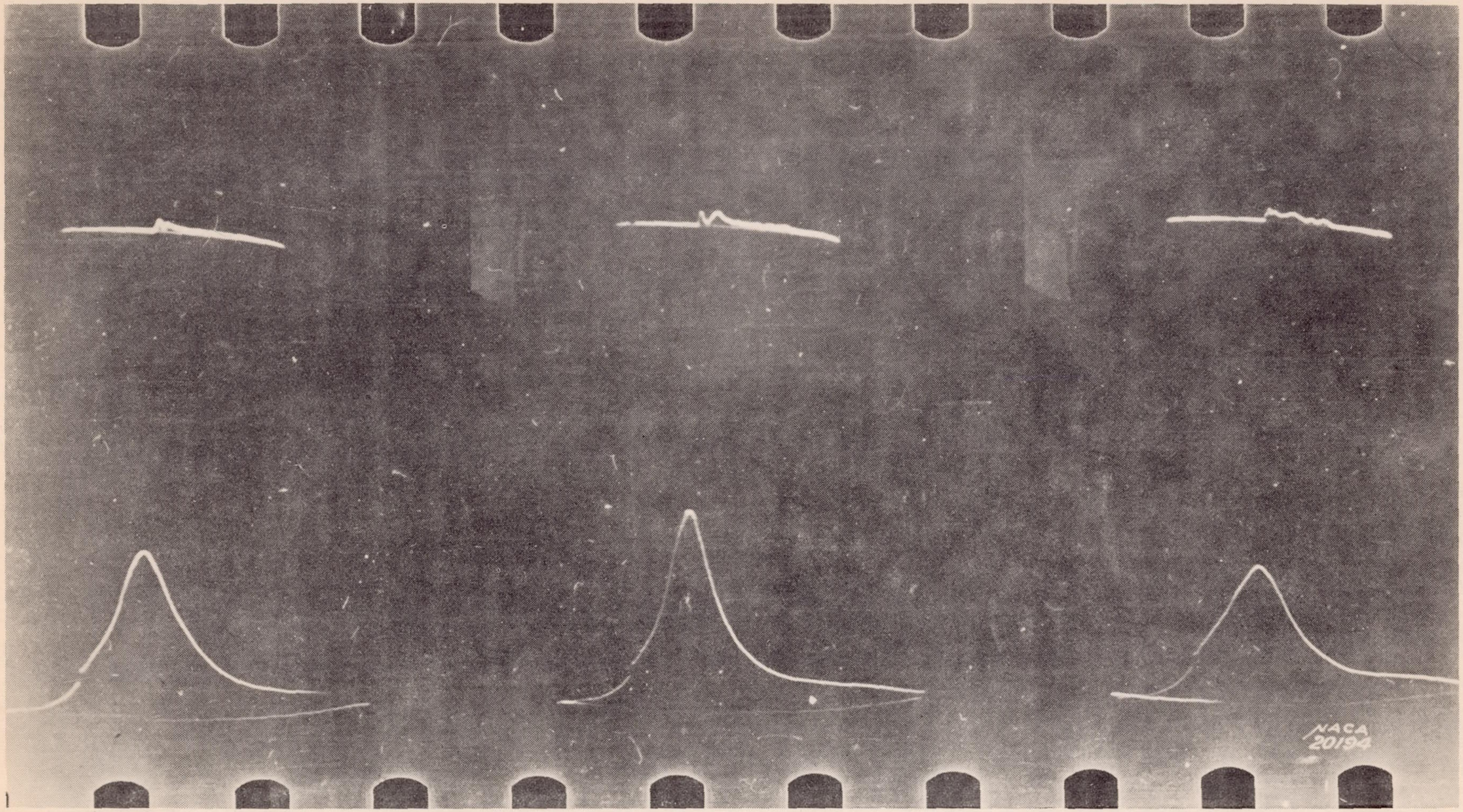

Figure 6.- Ionization-current and cylinder-pressure records of three successive cycles. No knock; fuel, S-1; mixture temperature, 200° F.

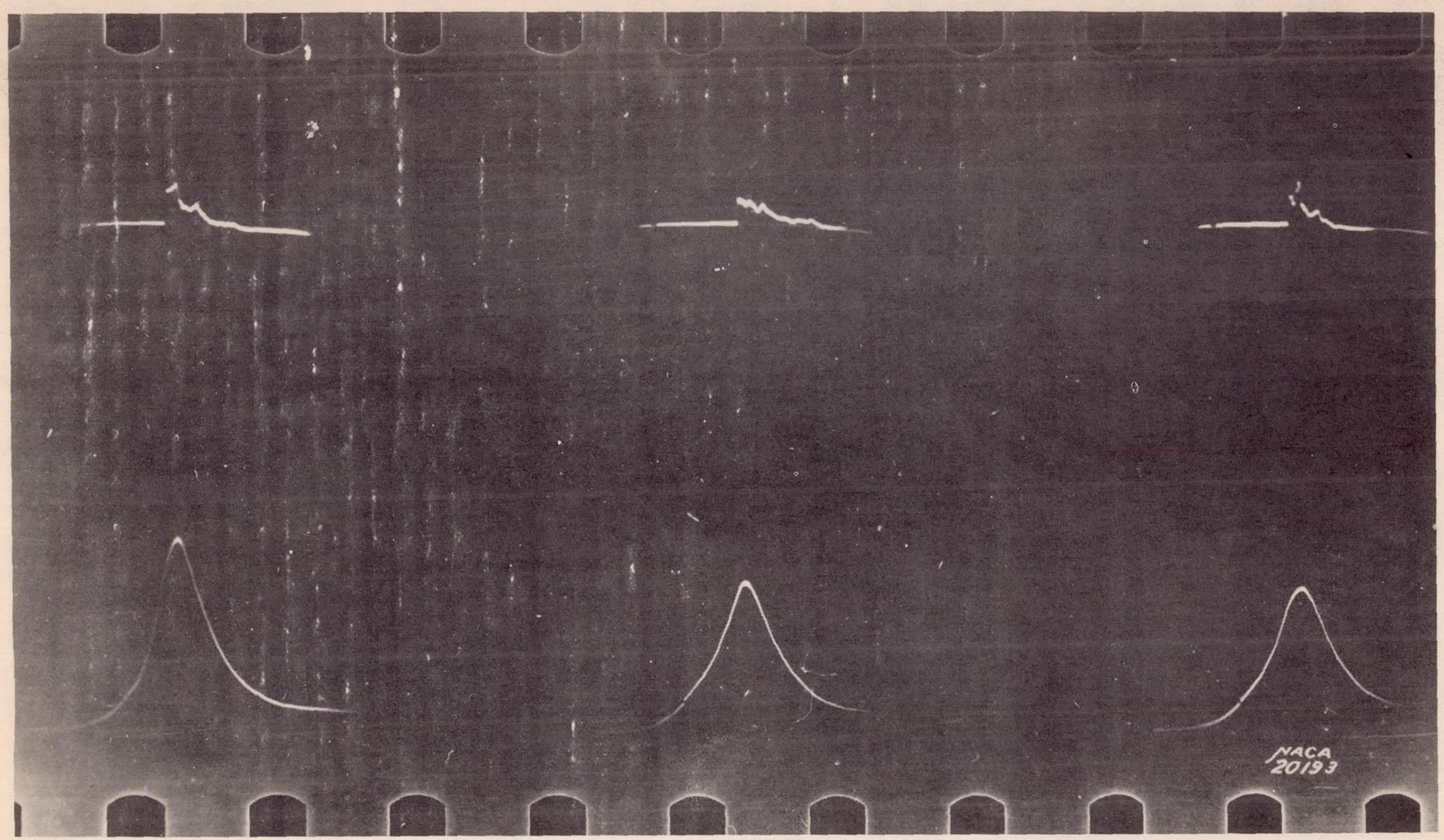

Figure 7.- Ionization-current and cylinder-pressure records of three successive cycles. No knock; fuel, 100 octane Army gasoline + 6 ml ethyl fluid; mixture temperature, 100° F.

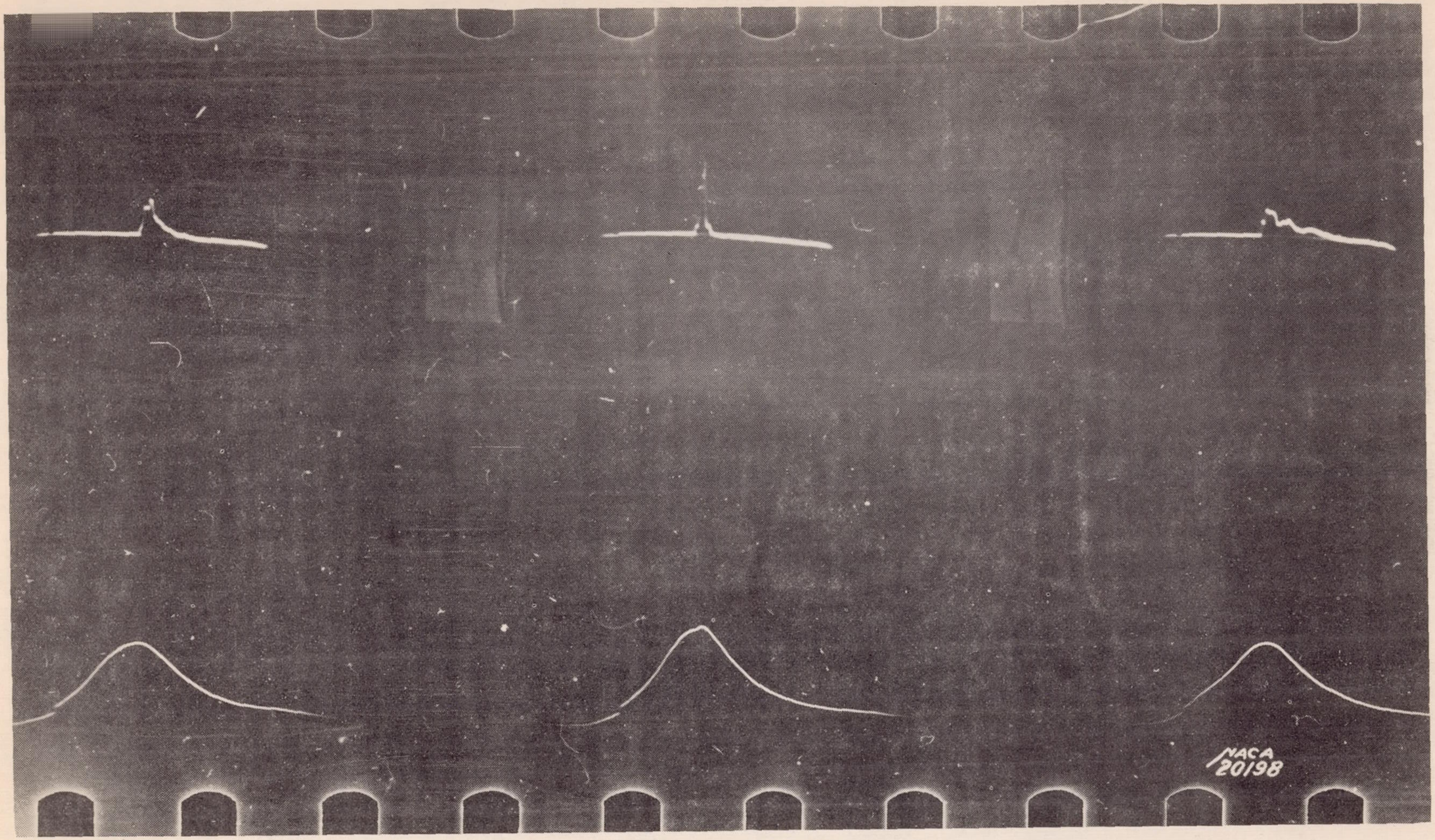

Figure 8.- Ionization-current and cylinder-pressure records of three successive cycles. Light knock in the second record; fuel, commercial gasoline (69 octane); mixture temperature, 100° F.

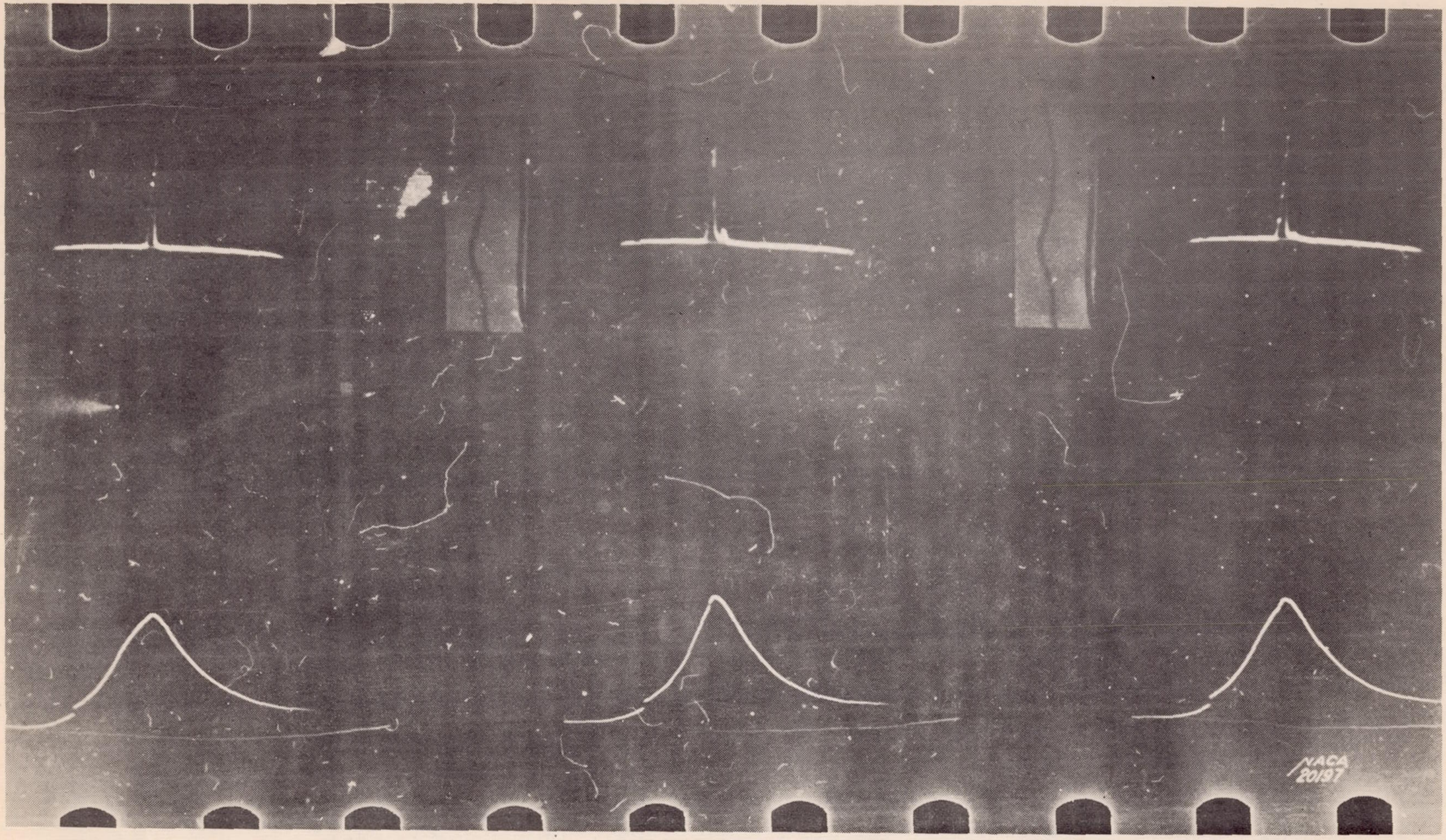

Figure 9.- Ionization-current and cylinder-pressure records of three successive cycles. Knock; fuel, commercial gasoline (69 octane); mixture temperature, 100° F.

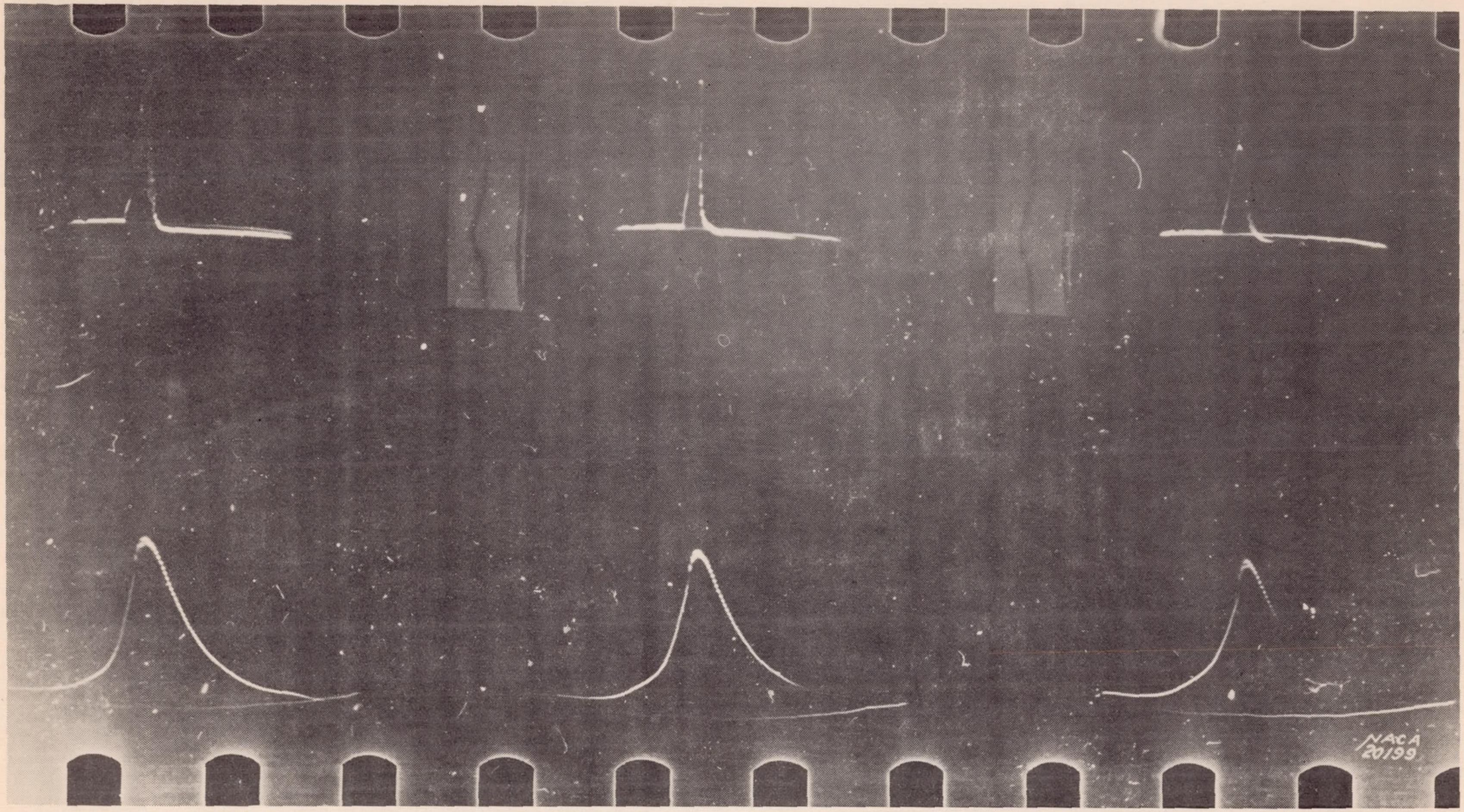

Figure 10.- Ionization-current and cylinder-pressure records of three successive cycles. Hard knock; fuel, commercial gasoline (69 octane); mixture temperature, 200° F.

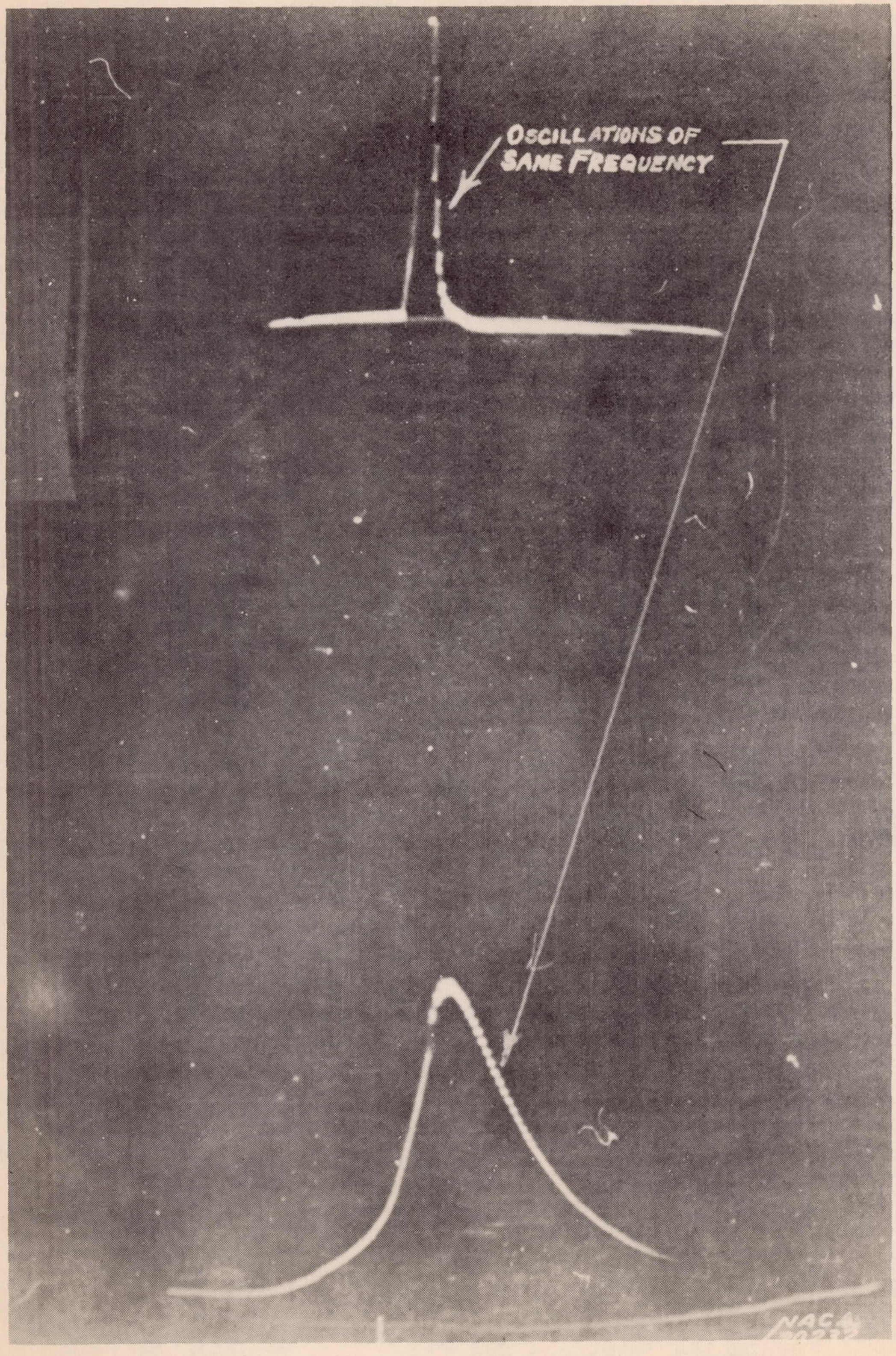

Figure 11.- Large-scale ionization-current and cylinder-pressure record of a knock cycle. Fuel, commercial gasoline (69 octane), mixture temperature, 200° F.